Life in the Universe

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If there was ever a question which men have pondered and not answered, the intriguing question of whether planets elsewhere in the universe harbor life is surely one of them. Does life, or more importantly, intelligent life, reside on other worlds in out Milky Way galaxy? The answer is not yet known. Whether life on other worlds exists or not isn't as significant as just knowing the answer--either case is important. Thomas Carlyle, in the nineteenth century put it this way, "[Other worlds offer] a sad spectacle. If they be inhabited, what a scope for misery and folly. If they be not inhabited, what a waste of space." [1] The question is certainly intriguing, but what can we really say about the possibilities of extraterrestrial life? What evidence can we find to help us? With knowledge from other fields related to exobiology [2]--physics, astronomy, chemistry, anthropology, geology, meteorology, and biology-we can speculate as to the nature and abundance of life on other worlds. This paper will explore what evidence is available and make some rather subjective, but scientifically based conclusions.

To begin with, we should first try to answer another difficult question. What is life? The fundamental handicap we face in attempting to answer this question is that out knowledge of life is restricted to essentially one example. The inner functions of all terrestrial organisms, however, are very similar, so some generalities can be made. Life is a continuing chemical process of a highly complex system, containing chains of carbon-based molecules which have the ability to grow and reproduce; this system is called a cell, and all organisms are assemblages of these cells which can replicate themselves by using the information in long molecules of deoxyribonucleic acid (DNA).

The basic building blocks of these organic molecules-carbon, hydrogen, oxygen, and nitrogen-are found throughout the universe in interstellar clouds. These basic elements were formed in massive stars and then ejected into space when they exploded as supernovae. Our sun, our planet, and ourselves were formed from such a cloud-we are made of star stuff. Even amino acids have been found in meteorites, showing that organic chemistry has been active in our solar system outside Earth. [3] These observations lead us to believe that since the basic building blocks of life exist elsewhere in the universe, then so might other carbon-based life.

If life does indeed reside in other parts of the universe, then how did it arise? This is another question which does not have a definite answer. We know, through original work by Louis Pasteur, that life arises from other life. But how did life begin on Earth? One hypothesis, called panspermia [4], proposes that life did not originate on Earth itself, but that living forms drifted from world to world, propelled by radiation pressure through interstellar space. Because of insuprerable obstacles such as radiation hazards during transit and geometrical difficulties, panspermia is not favorable. However, even if it could work, it only postpones the origin of life. So too, does the idea of seeding by another race of advanced beings. In any case, we must finally come to grips with the problem of an indigenous origin of life. To get a more clear understanding, let's take a look at our own beginnings.

The least understood segment of life's origin is the method by which inorganic molecules became self-replicating individual cells whose structure is determined genetically by DNA molecules enabling them to participate in further evolution by Darwinian selection. The important environmental factors for this to happen, though, are somewhat understood and seem to be: [5] (i) a primitive atmosphere containing a few percent hydrogen and no oxygen; (ii) the formation of a widely dispersed "primordial soup" of organic compounds and phosphates from energy provided by solar UV light, by lightning discharges, and from other sources, such as cometary nuclei influx; (iii) the formation of additional compounds within the soup as a result of continuing chemical reaction, aided by the concentrating effects of drying up or of freezing of pools formed by tidal action or rain; and (iv) the formation of polymers, probably on the surface of clays. Under these conditions, amino acids--constituent parts of proteins, and nucleic acids--can be created. "The stuff of life", Carl Sagan comments, "can be very easily made." [6]

Structures called coacervates, or spherical droplets, can form under such circumstances, and may have been important in isolating cell contents from the remainder of the pool. Another structure which can form in these pools are microspheres of polypeptides. We do not know in detail, however, how these structures may have evolved into the contemporary, reproducing cell. this process clearly requires a long period of natural selection; evidence suggests a period of about a billion years between the origin of life and the origin of the first cells. [7]

These early cells then evolved into even more complicated cells, called prokaryotes, which derived their energy from the fermentation of non-biological, organic materials in the primordial soup. Later prokaryotes developed photosynthesis, producing oxygen which poisoned unprotected anaerobic cells. This was the first great pollution of the environment, and it enabled aerobic organisms to develop. [8] This oxygen then allowed these more complex organisms, called eukaryotes, to use the critical importance of respiration--the oxidation of food stuffs as a highly efficient energy source. Oxygen also led to the formation of the protective ozone layer which blocks UV light. The rapid diversification of eukaryotic organisms, suggesting some form of sexual reproduction, then led to the emergence of multicellular forms of life. [8] More and more organisms eventually developed, through evolution by natural selection, and populated available niches. Now that the surface was protected from UV radiation, oxygen-consuming landlubbers could populate the Earth, leading eventually to intelligent life.

This view of the origin of life on Earth gives new insight into its generalities which can help us understand how life could originate elsewhere. Carl Sagan articulates it in this way: [9]

> *The evolution of life, by natural selection in response to the challenges of the environment, is increasingly well-documented in the fossil record. There is a general trend, as time progresses, towards enhanced complexity. Yet there is no reason to suspect any urge or desire towards complexity by the evolving organisms. We have seen that those mutants in the primitive environment which led to improved survival and replication of nucleic acids prospered; other molecular systems perished in enormous numbers. There is, accordingly, a sense in which the evolution of the cell, and all subsequent evolution up to man, may be viewed as a device for maintaining the continued survival of the nucleic acids. There is a sense in which our instincts and desires, our loves and hates, our breathing, eating, sleeping and dying exist because they help ensure the continued existence of the molecules of our genetic material; a sense in which we are fundamentally ambulatory repositories for our nucleic acids. Whether we like it or not this is at least in part what human beings are for; because of our intelligence we are more than this--but it is an open question how much more.*

From what we have just said, we can conclude that if planetary surfaces with the necessary conditions--liquid water and the "CHON" chemicals [10]--exist long enough anywhere, life is likely to evolve. But are there such planets? We have no conclusive proof that any planets exist outside our solar system; however, from the evidence available, we can guess that between %1 and %30 of all stars have at least one planet nearby. [11]

Let's now look at the conditions necessary to make a planet habitable: [11] (i) the central star should be between spectral classes F2 and K5 [12] so that it is large enough to keep the planet warm, and small enough so that it does not emit too much radiation, and that it lasts long enough for life to evolve; (ii) the planet must orbit at the right distance from the star so that water will normally remain liquid; (iii) the planet's orbit must be circular so that drastic seasonal changes do not occur [13]; and (iv) the planet must be large enough to hold an atmosphere, but not so large as to hold light gases (as gas giants do). We will try to estimate how many planets might satisfy these conditions later.

Another factor in the development of life on a planet involves the effects of astronomical processes on biological evolution. They may either encourage or hinder the evolution of life forms. A number of such processes have been identified that could cause massive climate changes that might affect the course of biological evolution. The important factors are: [14] (i) planetary convection causing plate tectonic crustal splitting, which changes sea levels, ocean currents, wind patterns, and seasonal extremes; (ii) volcanic activity can cause severe climatic changes by blocking sunlight from the surface; (iii) changes in the planets orbit also causes some climatic changes; (iv) slight changes in star radiation may cause climatic changes; (v) irradiation from a nearby supernova could have an effect on the climate or directly damage organisms; (vi) asteroidal or cometary impacts, or atmospheric explosions could damage the ozone layer and expose the surface organisms to enhance radiation;, and (vii) catastrophic asteroidal impacts can cause punctuated equilibria of biological evolution, enabling new species to fill the niche of extinct species (as mammals did when dinosaurs died out). All of this has happened on Earth, and despite the immediate effects, life proliferates here. These changes, while causing the decline of certain species, can have a beneficial effect by promoting the emergence of new species. this suggests that life can be very resilient to environmental changes, and that it could be abundant even on more changeable planets.

With what we now know about the origin of life on Earth and the conditions necessary for its development and continued existence, what can we say about life on other worlds? It is wise at this point to adopt a very conservative approach and confine out attention to planetary environments which could harbor life as we know it. For when we piece together the evidence of how life appears to have evolved on our own planet, we find nothing that could not happen elsewhere, given the right circumstances [15]. This will give us the largest chance of a successful estimate. We will also attempt to add the condition of intelligence to the life, because we have a reasonable chance of verifying that life exists elsewhere only if we can communicate with a civilization through the use of radio waves which travel at the speed of light.

The method of calculation by which we can estimate the number of such civilizations in the galaxy was first formulated by Frank Drake of Cornell University. The equation reads: [16]

$$N = N_S \times F_P \times N_P \times F_I \times F_C \times F_L$$

where N is the number of civilizations in the Milky Way with which we can communicate; the factors in the formula are:

	N_S - the number of stars in the Milky Way.
	F_P - the fraction of stars that have planetary systems.
	N_P - the number of planets in a given system that are ecologically suitable for life.
	F_B - the fraction of otherwise suitable planets on which life actually arises.
	F_I - the fraction of inhabited planets on which an intelligent for of life evolves.
	F_C - the fraction of planets inhabited by intelligent beings on which a communicative technical civilization develops.
	F_L - the fraction of a planetary lifetime graced by a technical civilization.

Each of these factors must now be estimated. The problem is that the later the factor appears in the equation, the less we actually know about it; the estimates of the later factors will be little more than guesses. Therefore, each factor will be given an optimistic and a pessimistic value. These are summarized in Table 1. Let's now take a look at each factor; we will estimate values based on what evidence is currently available. The reader is, however, invited to disagree with any chosen values and substitute his own choices to see how they will affect the value of N.

By careful counts of stars in small, but representative regions of the sky, we can find the number of stars (N_S) on our galaxy. The number is between 10^{11} and 10^{12}; in this case we will assign only one value; let's use $N_S = 4x10^{11}$.

Even with today's technology, we still don't have direct observations of planets in orbit around any star other than our own. There is, however, indirect evidence that planets are a frequent accompaniment of star formation: in the satellite systems of Jupiter, Saturn, and Uranus, which are like miniature solar systems; in theories of the origin of the planets; in studies of double stars; in observations of accretion disks around stars; and in some preliminary investigations of gravitational perturbations of nearby stars.[18] Many, perhaps even most, stars have planets. we will take for the fraction of stars with planets, F_P, as between 0.01 - 0.3.

The number of habitable planets in our solar system is at least one. If we are optimistic, Mars and Titan are also suitable for life. Factors now are becoming less reliable; in this case 0.1 may be far too conservative, and 2.0 is very optimistic. We can, however, choose these as out upper and lower limits. So N_P is between 0.1 and 2.0.

As we have seen, experiments show that under the most common conditions, the molecular basis of life is readily made. But what are the chances that these molecules evolve a genetic code which can make copies of itself? We are uncertain; there may be some impediment in the evolution of the genetic code, although it is probably unlikely over billions of years of primeval chemistry. We will choose F_B, the fraction of planets on which life actually arises, as between 0.1 and 1.0.

For F_I, the fraction of the planets with life which develop intelligence, a time scale seems to be important. We are interested in the times required for evolution by natural selection to produce intelligent beings with a capability for communicating across interstellar space. The transformation from prokaryotic single cell life forms to eukaryotic single cell life forms took about 2 billion years; this evolution occurred in liquid water at a temperature near 20-40^oC. This temperature is important. The speed of agitation of atoms and molecules increases as the temperature is raised, and thus the rate of chemical reactions. there is a factor of about 2 of speeding up of chemical reactions for every 10^oC increase in temperature. Therefore, the temperature is an important factor in determining whether or not intelligent life will be able to develop within the lifetime of the planet.[19]

Another important factor for determining F_I is the variability of the environment. Evolution seems to occur at times of change of the environment experienced by a species. As we have seen in our discussion of habitable planets, astronomical processes can change the environment enough to cause punctuated equilibria of species. For evolution to go a long way on a planet requires a very changeable environment--such as land environments. During the last 1 million years, when the ice caps were most active, a great deal of human evolution occurred. This was, of course, very important to the development of intelligence on Earth.

So, all of these variable factors make the determination of F_I difficult. On the one hand, there must be quite different pathways to an advanced civilization. Let's choose the lower limit of F_I as one in ten. And, considering the Earth to be a typical example, we choose the upper limit to be unity--all planets which develop life, also develop intelligence.

The next factor, F_C, the fraction of planets inhabited by intelligent beings on which a communicative technical civilization develops, is again more speculative. Once humans developed speech and societies, transfer of information between individuals became possible; this began a gradual accumulation of knowledge which eventually led our modern science and technology--only about 10,000 years were necessary. But intelligent beings do not necessarily develop technology even if they are capable of communication with each other. The dolphins, for example, have an elaborate speech system, but because they do not have fingers to keep records and do experiments, the transition to a technical society is difficult for them. Another important point here is that a society may have little interest in communication with other worlds; many reasons can be imagined for this isolationism. However, any society which does develop scientific technology, would certainly discover radio communication. Again, reasonable values for F_C seem to be between 0.1 and 1.0[20].

There are great uncertainties in the final factor F_L. How long, in relation to the lifetime of the planet itself, does a technological civilization endure? We have practiced radio astronomy for only about 50 years; a mere on millionth of a percent of Earth's existence. Sagan remarks:21

> *If civilizations tend to destroy themselves soon after reaching a technological phase, there might be no one for us to talk with but ourselves. And that we do but poorly. civilizations would take billions of years of tortuous evolution to arise, and then snuff themselves out in an instant of unforgivable neglect.*

But if at least some civilizations learn to live with high technology, they might live to a prosperous old age. So, given these very complex determinants, we might assign a sadly pessimistic value of one millionth of one percent ($F_L = 10^8$); a reasonable optimistic value might be as high as one percent ($F_L = 0.01$).

Now we can calculate N, the number of civilizations in the Milky Way Galaxy with which we can communicate. As shown in Table 1, the pessimistic value of N turns out to be 0.004; this is chiefly due to the factor concerning technological endurance. the value of N, of course has to be a positive integer, so a value of 0.004 simply means that in only 1 out of 250 solar systems in our galaxy holds a civilization capable of radio communication. The optimistic number is 2.4×10^8--about 2.5 billion. It seems that the only thing that might keep us from talking with other beings is adolescent ignorance of the use of weapons of mass destruction. Sagan comments:[22]

> *Thus, for all our concern about the possible unreliability of our estimates of the early factors in the Drake equation which involve astronomy, organic chemistry and evolution, the principal uncertainty comes down to economics and politics and what, on Earth, we call human nature.*

Let's also look at the distances to these other members of the "Galactic Club". If there is only 1 civilization in 250 solar systems we can talk with, then the mean distance would be about 10 million light years. This is too far even for radio communication; any civilization which sent out a message would be long gone (and maybe us too) by the time it got to us (recall our estimate of its communicative lifetime was only about 100 years). In this case though, we could still benefit by receiving in intelligible transmission from them. However, if intelligence does indeed abound throughout the Milky Way, as by our optimistic estimate, then the nearest could be as close as 15 light years. they are not only close enough to talk with but, even at speeds well below the speed of light, they live close enough to us for practical interstellar visits.

Even though the above estimates contain a great deal of uncertainty and in some cases are depressingly pessimistic, other considerations which we did not look at do exists. We only considered carbon-based life as we know it here on Earth--other types may exist. Also, intelligent societies also might have an insatiable desire to colonize other worlds, thus filling the galaxy planet by planet and increasing out chances of bumping into them.

We have seen that life, even restricted to forms with which we are familiar, can and probably does exist on other planets, circling other stars, in other solar systems. In the pessimistic estimation, the closest civilization lives in another solar system 10 million light years away. Nonetheless, there are so many galaxies, that it is hard to avoid the conclusion--even with the pessimistic view--that **life outside the solar system is likely**, with millions of billions of technical civilizations.[22]

Discovery of firm evidence for alien civilizations, or even alien life forms, could be a pivotal development in our view of ourselves and the cosmos. Yet the study of exobiology can still give us some idea as to the nature and abundance of life in the universe. Experimental evidence strongly indicates that life should start on other planets with environments similar to Earth's. Astronomical evidence suggests that other habitable planets ought to exist elsewhere. Biological evidence shows that life is adaptable and species can evolve to fit different environments. We might someday know the answer to whether or not other life exists in the universe. Albertus Magnus of the thirteenth century wrote, "Do there exist many worlds, or is there but a single world? This is one of the most noble and exalted questions in the study of Nature."[24]

Notes

1. William K. Hartman, *Astronomy, the Cosmic Adventure*, Belmont, California: Wadsworth Publishing Company, Inc. 1985, p.470.
2. Exobiology is the study of life beyond the earth.
3. Hartman, p.466.
4. Carl Sagan and I.S. Shklovskii, *Intelligent Life in the Universe*, San Francisco, California: Holden-Day, Inc., 1966, pp.207-212.
5. Brian Tinsley, Class notes for Astronomy, PHYS 3380, fall semester, UTD, 1985, pp.6-7.
6. Carl Sagan, *Cosmos*, New York: Ballantine Books, 1980, p.27.
7. Sagan and Shklovskii, p.241.
8. Tinsley, p.7.
9. Sagan and Shklovskii, pp.244-245.
10. "CHON" chemicals are carbon, hydrogen, oxygen, and nitrogen.
11. Hartman, p.476.
12. These are suitable main sequence stars similar to our sun.
13. Such an orbit is even possible in common types of binary star systems.
14. Hartman, p.478.
15. Tinsley, p.4.
16. Sagan, p.248.
17. $10^2 = 10 \times 10$
18. Sagan, p.248.
19. Tinsley, pp.9-14.
20. Tinsley, p.14.
21. Sagan, p.250.
22. Sagan, pp.250-251.
23. Even with the estimate of one civilization in 250 galaxies, one can look toward the constellation Hercules and be assured of seeing the light from a star which has a planet containing intelligent beings.
24. Sagan, p.111.

Table 1. Estimated Number of Advanced Technical Civilizations in the Galaxy

		Plausible Lower Limit	**Plausible Upper Limit**
N_S	Number of stars in the Milky Way Galaxy.	4×10^{11}	4×10^{12}
F_P	Fraction of stars that have planetary systems.	0.01	0.3
N_P	Number of planets in a given system that are ecologically suitable of life.	0.1	2.0

F_B	Fraction of otherwise suitable planets on which life actually arises.	0.1	1.0
F_I	Fraction of inhabited planets on which an intelligent form of life evolves.	0.1	1.0
F_C	Fraction of planets inhabited by intelligent beings on which a communicative technical civilization develops.	0.1	1.0
F_L	Fraction of a planetary lifetime graced by a technical civilization.	10^{-8}	0.01
Product	Number of civilizations in the Milky Way Galaxy with which we can communicate (N).	0.004	2.4×10^9
Implication	Distance to the nearest civilization.	10^7 ly	15 ly